ESD-TR-71-248

Quarterly Technical Summary

Air Traffic Control

15 August 1971

Prepared under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

Quarterly Technical Summary

Air Traffic Control

15 August 1971

Issued 20 September 1971

Prepared under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the Department of the Air Force under Contract F19628-70-C-0230.

INTRODUCTION

This report describes the activities in Air Traffic Control which are funded by the Air Force. Where these activities have led to projects supported by other agencies or are intimately related to such work, this interrelationship has been noted.

Progress on other ATC tasks during this quarter included the completion of a Technical Development Plan for a Discrete Address Beacon System for the FAA, two studies relating to Fourth Generation ATC System Concepts for the Transportation Systems Center of DOT, and the Evaluation of a Laser Beam Alerting System for Logan Airport sponsored by the Massachusetts Port Authority. These efforts are being reported separately.

H. G. Weiss
Head, Division 4

15 August 1971

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

CONTENTS

ORGANIZATION

DIVISION OFFICE

Herbert G. Weiss, *Head*
Francis X. Brady, *Assistant*

GROUP 41

Paul R. Drouilhet, Jr., *Leader*
Melvin L. Stone, *Associate Leader*

J. W. Andrews
H. Berger
J. U. Beusch
H. Blatt
R. W. Bush
G. V. Colby
E. J. Denlinger
V. S. Dolat
J. E. Evans
T. J. Goblick, Jr.
J. R. Johnson
J. L. Katz
E. J. Kelly, Jr.
W. D. Lanning
R. J. McAulay
J. L. Meiry
J. H. Nuchols
A. F. Pensa
J. M. Ruddy
K. S. Schneider
I. G. Stiglitz
J. D. Welch
M. L. Wood

Collaborative Laboratories on the M.I.T. Campus:

Flight Transportation Laboratory – Aeronautics and Astronautics Department
Electronic Systems Laboratory – Electrical Engineering Department
Man-Vehicle Control Laboratory – Aeronautics and Astronautics Department

AIR TRAFFIC CONTROL

I. SUMMARY

The Lincoln Laboratory Air Traffic Control research program is exploring new concepts, techniques and instrumentation to improve the ability of the current and projected national system to handle air traffic efficiently and safely. Currently, major efforts are directed toward improving the surveillance and communications elements of the ATC system. That portion of the overall program which relates specifically to Air Force requirements in Air Traffic Control is reported.

Recent progress in the area of Surveillance Technology, including investigations of ATC Radar Beacon System (ATCRBS) Transponders and Radar Tracking, is reported in Sec. II.

Work is continuing on the Systems Engineering and simulation studies of an airborne traffic display which will provide pilots with an integrated air traffic and navigation capability. In addition, a cost-benefit study of an airborne traffic display operating as an adjunct to the advanced Third Generation ATC System was initiated for the Aviation Advisory Commission. This work is described in Sec. III.

A study was initiated in July to develop a program plan for acquiring the detailed data on propagation effects that are needed in the design of a Communications, Navigation and Identification System (CNI). This task is supported by the Communications Development Division of ESD and is reported in Sec. IV.

A study of the two candidate Microwave Landing Guidance Systems was initiated, with emphasis on defining the basic system parameters for the doppler scanning system. This effort will be reported in our next quarterly technical summary.

During the past quarter, a computerized access system was established for the growing collection of documents pertaining to air traffic control. The document retrieval system is an extension of the Lincoln Laboratory's LISTAR Program.

II. SURVEILLANCE TECHNOLOGY

During the past quarter, major emphasis continued on the preparation of a Technical Development Plan for a Discrete Address Beacon System (DABS) under the sponsorship of the Federal Aviation Administration (FAA). This task is now complete. Our investigation of ATCRBS transponders was expanded with FAA support to include field tests of general aviation transponders. Radar tracking studies continued in close coordination with related efforts at Lincoln Laboratory.

Because of its relevance to ATC we have continued to maintain interest in the application of the high resolution, electronically scanned radar system recently assembled by the MTI Radar Group. This radar is now radiating and its digital processor is being debugged. During the coming quarter, this equipment will begin operating as a complete system for ground surveillance. Studies of its performance as a radar test bed for all-weather, clutter-free monitoring of air traffic are continuing.

A. ATC Radar Beacon System Development

1. Interrogator Antenna Studies

Possible applications of monopulse antenna systems are of continuing interest for use in the upgraded Third Generation ATC System. The accurate target angle measuring capability from a single return with monopulse should be valuable in the ATC environment. The potential angle estimation accuracy σ_φ of an amplitude monopulse system has been studied in depth. Some of the interesting conclusions obtained are:

(a) Only when the noise power in the sum and difference channels is unequal can improvement be obtained by forming the sum and difference signals at IF, rather than at RF. However, the improvement is substantial only when the above two noise powers differ greatly, a situation that does not occur frequently.

(b) σ_φ on and near boresight is dependent essentially upon the ratio of the signal in the sum channel to the noise in the difference channel, and is independent of the noise power in the sum channel (in the high signal-to-noise case). This is intuitively reasonable, but does not appear to have been demonstrated in the prior literature.

(c) Far off-boresight σ_φ is not affected by the noisier channel, no matter how great the difference.

2. Transponder Studies

Previously reported work addressed the problem of false triggering of the present generation of ATCRBS transponders by various proposed DABS modulation formats. Laboratory tests of one military and two general aviation transponders provided some limited practical data.

The study of transponders moved from the laboratory to the field during the past quarter. Supported by the FAA, a program of field measurements was undertaken to determine in situ the operating characteristics of general aviation transponders. Parameters of interest included frequency, dead time, suppression time, delay, power output and sensitivity.

A total of 96 general aviation transponders, installed in aircraft based at various airports around Boston, have been tested to date. The resulting data are currently being reduced and will be contained in an interim report to be published in September. The FAA is presently reviewing the initial results to determine what further testing, if any, is desirable at this time.

B. MTI Studies

Significant improvements in the clutter rejection performance of radars have recently been achieved through the use of digital signal processing (DSP) techniques. A study of the Air Route Surveillance Radar (ARSR) clutter problem was undertaken to determine whether or not these advances could be useful in improving the signal in clutter detection capabilities for the ATC enroute radars. In the process of developing a rational analytical basis on which to evaluate the well-known MTI processors, an optimal receiver structure was derived. In Fig. 1 the signal-to-interference ratio (SIR) at the output of the various receivers is plotted as a function of target velocity for the ARSR system parameters. A practical receiver that achieves almost optimal performance can be implemented using DSP techniques

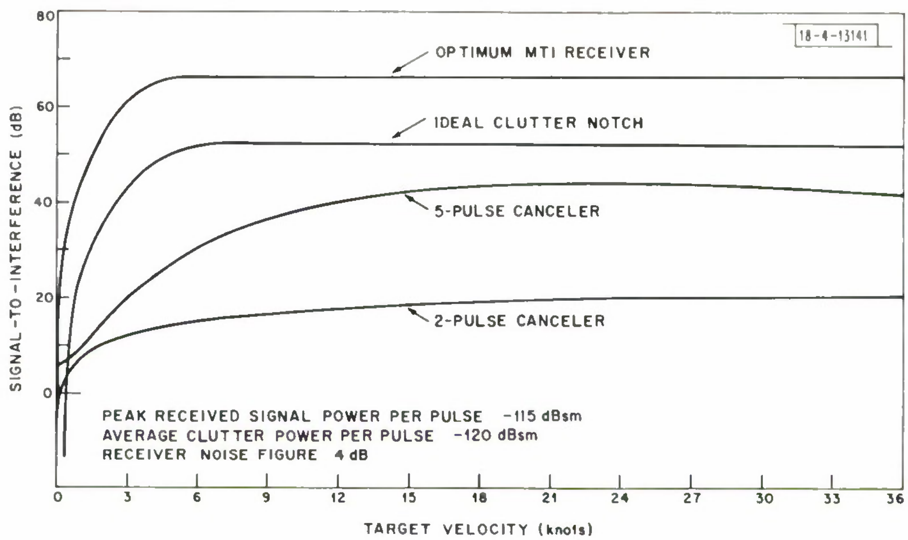

Fig. 1. Signal-to-interference (clutter plus receiver noise) vs target velocity for uniformly spaced transmissions.

The results in Fig. 1 apply when the transmitter operates in a non-staggered mode, which implies that the null in the SIR curve at zero velocity folds over at the prf. For the ARSR this is 260 Hz, which corresponds to blind speeds at n · 72 kts, n = 1, 2, 3, ... It is standard practice in MTI technology to eliminate the blind speeds by staggering the transmitter prf. A mathematical analysis of this problem was also undertaken and an optimum receiver structure was developed. The SIR performance for the optimum two-pulse staggered system is shown in Fig. 2. In addition to improving the target detectability at the former blind speeds, it was discovered that the optimal processor can estimate target velocity unambiguously out to 350 kts. This interval can be widened further by staggering more pulses in the transmitter sequence.

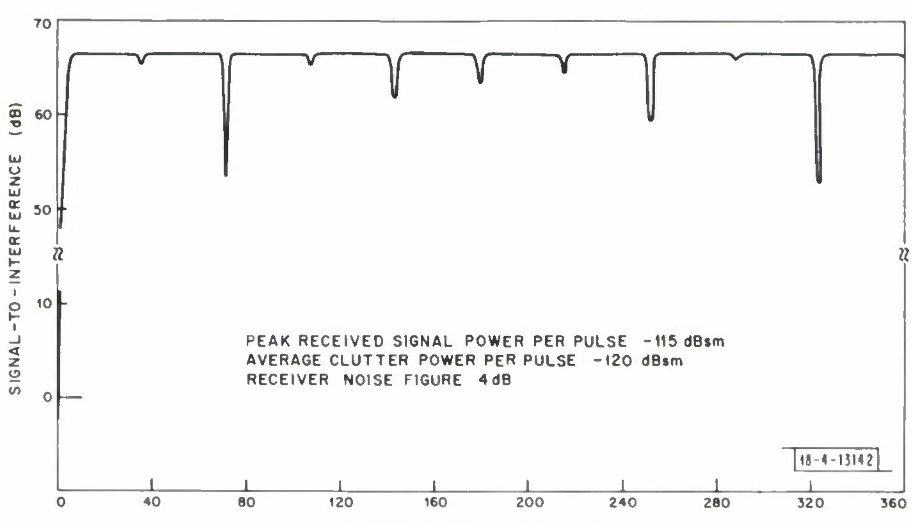

Fig. 2. Optimum signal-to-interference vs target velocity for two-pulse staggered prf.

Therefore, by carefully designing the multi-staggered transmissions of the ARSR, an MTI receiver can be implemented using DSP techniques to improve target detectability in clutter by 10 to 20 dB and simultaneously to generate unambiguous velocity estimates while maintaining 200 nmi unambiguous range. The receiver synthesis, analysis and MTI signal design problems are documented in a forthcoming technical note.

III. AIRBORNE TRAFFIC SITUATION DISPLAY

The concept for an airborne traffic situation display system which is under investigation would provide pilots with a CRT display of adjacent air traffic labeled with identification, altitude and ground speed. It would also present relevant map data, including navigation fixes, airways, obstructions and weather contours. The data for this display would be transmitted over a narrow-band data link from the ground-based NAS/ARTS equipment presently being installed.

A. Design Studies

During this quarter, work continued on construction of the waveform generator module of the experimental traffic display system. Construction and checkout of this module and of the experimental CRT indicator module is scheduled for completion during the coming quarter.

B. Display Simulation (Electronic Systems Laboratory, Flight Transportation Laboratory, Man-Vehicle Control Laboratory)

Thesis research by M.I.T. graduate students was completed in June. This work utilized a cockpit simulator assembled by the above M.I.T. Campus laboratories to assess the human factors aspects of the display and its value as a flight instrument, particularly in operations in the terminal area. Two thesis reports have been published.*

C. Cost Benefit Analysis

This study, initiated on 1 July under the sponsorship of the Aviation Advisory Commission, will assess the cost benefit of the traffic situation display. The results of this study will be submitted to the Commission early in 1972.

D. Future Research

The experimental TX-2 computer, which was built by the Digital Computer Group (Division 2) of Lincoln Laboratory, has many computational and man-machine interfacing features which make it particularly useful in performing simulation experiments involving extensive interactions between the computer and an operator. As an example of this capability, a simulation of air traffic in a terminal area has recently been programmed on TX-2. The scope (Fig. 3) is organized in a manner similar to the display seen by air traffic controllers, and the operator may issue commands to change parameters such as heading, altitude and speed. A table of characteristics of various aircraft is used to generate realistic presentations of their performance in

---

* R. E. Anderson, "Format Evaluation for an Air Traffic Situation Display," M. S. Thesis, Department of Aeronautics and Astronautics, M.I.T. (June 1971); T. Imrich, "Concept Development and Evaluation of Airborne Traffic Display," M. S. Thesis, Department of Aeronautics and Astronautics, M.I.T. (June 1971).

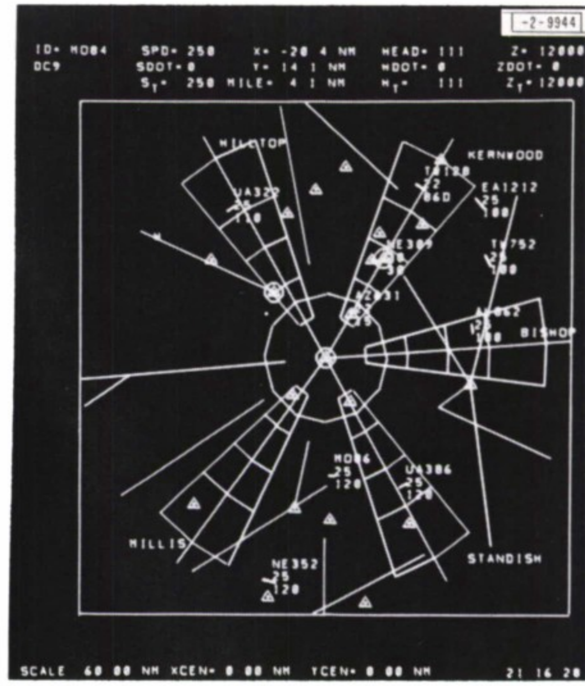

Fig. 3. Typical display produced by air traffic simulation program. Aircraft are represented as radar slashes 4° wide, with alphanumeric information to identify flight number, speed and altitude. At top of screen is detailed information regarding one specific aircraft. The controller can readily issue commands and edit his display using an interactive graphics tablet.

all flight modes. A script of arrivals and departures may be provided to the program or generated by the operator as he goes. A facility for replaying an entire session has been provided, as well as a "snap-shot" facility for saving the instantaneous state of the system. The intent of the demonstration program was to evaluate proposals for several different airway configurations around an airport by having controllers run through identical scripts of arrivals and departures and record the time and mileage for each aircraft in the system.

This capability will be employed in the future evaluation of air traffic control problems.

IV. COMMUNICATIONS, NAVIGATION AND IDENTIFICATION SYSTEM STUDY

Under the sponsorship of ESD, a study was initiated to understand in detail the impact of propagation phenomena on the choice of a modulation scheme for use in CNI systems. A variety of links, including air-to-air, air-to-ground and various paths involving satellites, will be evaluated along with the combination of operating modes and propagation effects.

The information acquired during the initial period of this study can be summarized in two interrelated ways: (1) by basic phenomena that affect one or more channels and (2) by effects related to the individual CNI channel.

The basic propagation phenomena can be conveniently catalogued in three broad classes. These are: surface-reflected multipath, atmospherically caused effects and aircraft-produced effects (e.g., multipath encountered with large airframes can have differential delay times on the order of 10 to 250 nsec).

Major emphasis has generally been placed on surface reflected multipath as the predominant propagation phenomena in affecting CNI channels. However, past experiments have demonstrated that other classes of propagation phenomena can be of equal importance. For example, radio holes (deep signal reduction below that expected from inverse distance predictions) have been

observed on numerous air-to-air and air-to-ground links. The reductions in signal are on the order of 5 to 30 dB and can occur continuously over a distance of 5 to 60 miles. They are (to first order) independent of frequency and have been experimentally observed simultaneously over 2 GHz, in some cases. Meteorological measurements have shown that the atmospheric conditions leading to these effects can be present as much as 60 percent of the time in some regions during certain months. All three classes of propagation phenomena can have significant effects on the performance of a CNI system and hence require careful evaluation. However, thc aircraft-related effects can be most meaningfully studied in the context of specific aircraft and aircraft antennas.

In the following months, work will be directed toward considering the electromagnetic propagation phenomena mentioned above. The effect of these phenomena on the signal in the channel has been traditionally represented as a linear time-varying filter, with random and deterministic elements, and additive noise. A number of interpretations for the filter parameters and the physical circumstances under which the parameters provide meaningful characterization of the channel will be studied. Further documents on relevant past propagation studies are still being received and will be reviewed.

DOCUMENT CONTROL DATA – R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Lincoln Laboratory, M.I.T.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP None
3. REPORT TITLE Air Traffic Control	
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Quarterly Technical Summary, 1 May through 31 July 1971	
5. AUTHOR(S) *(Last name, first name, initial)* Weiss, Herbert G.	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 August 1971	16	2

8a. CONTRACT OR GRANT NO. F19628-70-C-0230 b. PROJECT NO. 649L c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Air Traffic Control QTS 15 August 1971 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ESD-TR-71-248
10. AVAILABILITY/LIMITATION NOTICES Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY Air Force Systems Command, USAF

13. ABSTRACT

This report describes the activities in Air Traffic Control which are funded by the Air Force. Where these activities have led to projects supported by other agencies or are intimately related to such work, this interrelationship has been noted.

Progress on other ATC tasks during this quarter included the completion of a Technical Development Plan for a Discrete Address Beacon System for the FAA, two studies relating to Fourth Generation ATC System Concepts for the Transportation Systems Center of DOT, and the Evaluation of a Laser Beam Alerting System for Logan Airport sponsored by the Massachusetts Port Authority. These efforts are being reported separately.

14. KEY WORDS

air traffic control	Automated Radar Terminal System (ARTS)
data acquisition	Air Traffic Control Radar Beacon System (ATCRBS)
communications	Discrete Address Beacon System (DABS)
surveillance	